Simulating Transport and the Economy: The Urban Dynamic Model

Introduction
This paper describes a land-use and transport interaction model that has been developed in the UK and used extensively in strategic planning projects there. The innovative aspect of this model lies in both the policy context in which it is designed to be used, and in the technology with which it is built, integrating network modelling techniques with the dynamic simulation technique known as system dynamics.

The history of system dynamics, which first appeared in the late 1950s, has been somewhat chequered. Jay Forrester developed an early simulation of an urban area back in 1969, and it proved highly controversial, as did many of his writings. The aim of this paper is not to rehearse these arguments again, but to present system dynamics at face value, as a simulation tool supported by excellent modelling software, to show how it can be used to address transport modelling problems, and to demonstrate a successful track record in doing so.

System Dynamics: Some Background
System Dynamic is a form of computer simulation. It treats time as continuous, and simulates how conditions change as the entities in the model interact with each other.

There are two building blocks in SD models: stocks and flows. Stocks are accumulations of ‘stuff’, while the flows are the rates at which stocks are added to or depleted. Stocks are often physical entities – people, businesses, journeys - but they can also be more abstract, such as mode shares, or measures of preference. SD models are assemblages of linked stocks and flows, built using software that simulates how the entire system changes through continuous time.

Because of their distinctive formulation, SD models have important characteristics, notably their ability to handle feedback. Feedback occurs when decisions made at one point in time have consequences that, later on, to alter the conditions that led to those original decisions: improved transport conditions inducing more traffic that causes congestion that worsens conditions is an example that comes to mind. This is hard to handle in equilibrium models, especially where multiple feedbacks operate with different lags, but by addressing feedback properly we gain the chance to understand much deeply how a system really behaves and how it is likely to respond to policy changes in the long and short term.

Closely related is SD’s focus on how people make decisions and the information they use to make them. Transport modellers will be familiar with logit models, widely used for choice of mode, time of day, route etc, and these can be incorporated in SD models (the UDM uses many of them). However a system dynamics model can recognise that people take time to learn about changes to conditions and to respond to them. Recognition of the gap between instantaneous ‘real’ conditions and the time for people to respond is the key to formulating feedback models.

The Urban Dynamic Model

The Urban Dynamic Model simulates the interaction between land use, population, employment and transport over long periods of time (ie 10 years or more) to help answer questions about how transport investment can help economic growth and urban renewal. Originally developed in 2000, the model has been used in the UK on 16 projects, during which time it has undergone continuous development and improvement.

The UDM divides a study area into zones, each stocked with households, people, workers, houses, employers, jobs, employment premises and land. Zones are linked together via multi-modal transport networks representing highways (with congestion), bus, rail, walk and cycle.

A key idea behind the model is of the attractiveness of each zone as a place to live or to do business. The model maintains indices of attractiveness, and simulates how people and employers react as attractiveness changes. Employers are assumed to respond to the availability of premises, the ability to recruit a workforce and access to customers and suppliers; households respond to the availability of housing and employment. Transport is directly related to attractiveness because it affects the ability of employers to recruit, the access businesses have to customers and suppliers, and the range of employment opportunities available to the resident workforce.

Figure 1 is an overview of the UDM's structure showing how some of these processes operate within the model. The blue arrows indicate the causal sequence in which calculations are made, while some of the model's stocks are indicated in boxes.

The heavy lines pick out some of the processes and feedbacks. Starting at the top, transport investment reduces transport costs[1]; this increases the workforce[2] accessible to employers and improves access to other customers and suppliers; these both increase a location's attractiveness for employers, leading to an increase in the net business start-up rate and hence to the stock of businesses; however this generates more traffic, adding to congestion and increasing transport costs.

[1] For simplicity, infrastructure is represented here by a single stock, but the model has a much more complete representation of networks, times and costs.
[2] The minus sign at the head of this arrow indicates that accessible workforce tends to move in the opposite direction to costs; as costs *fall*, accessible workforce *rises*, and vice versa.

Figure 1: Sequences of Cause and Effect in the UDM

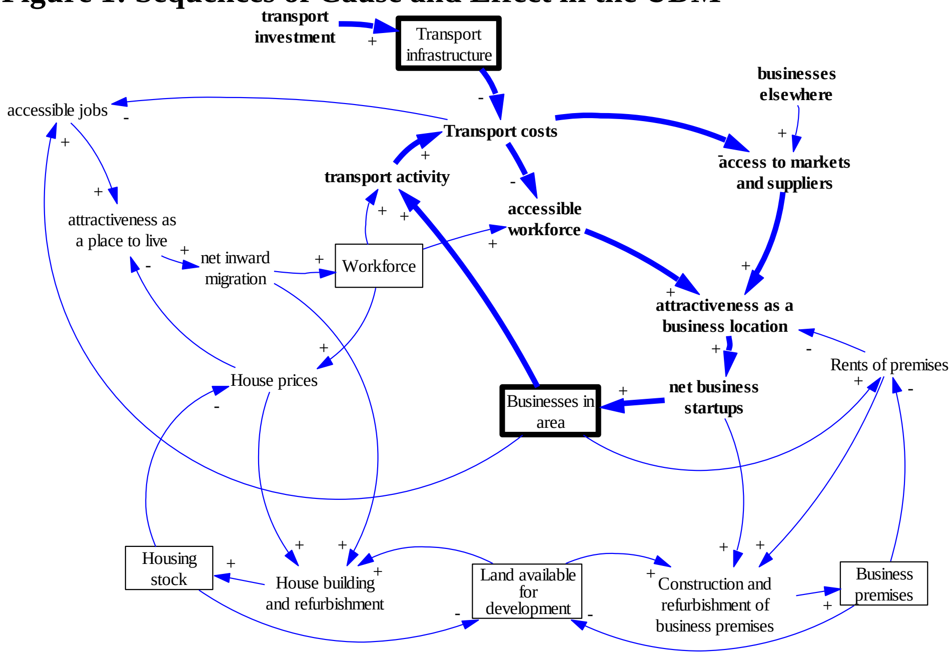
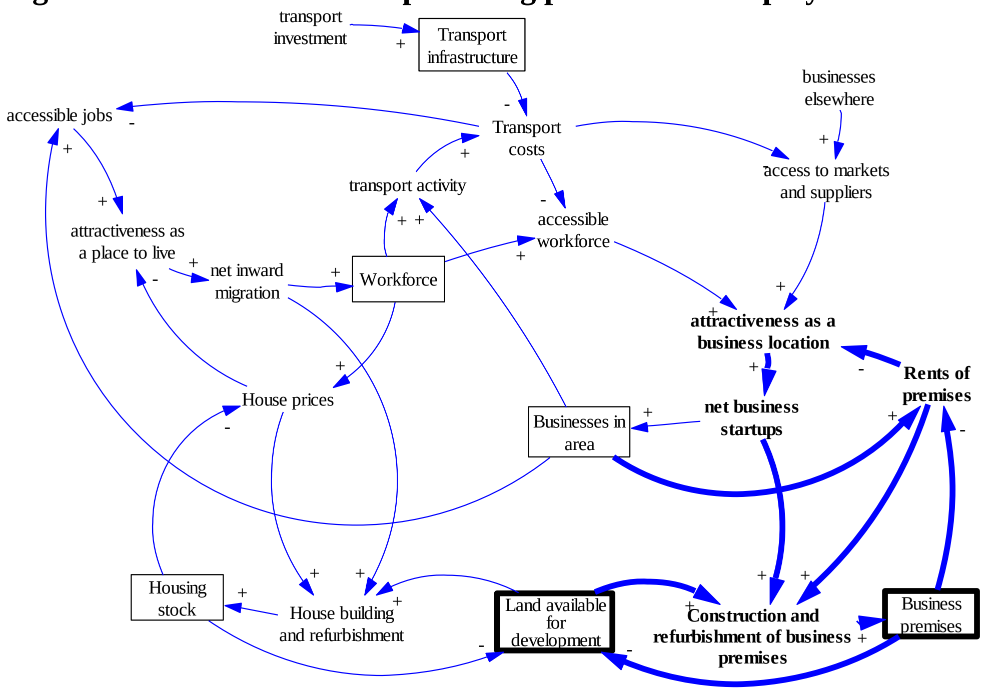


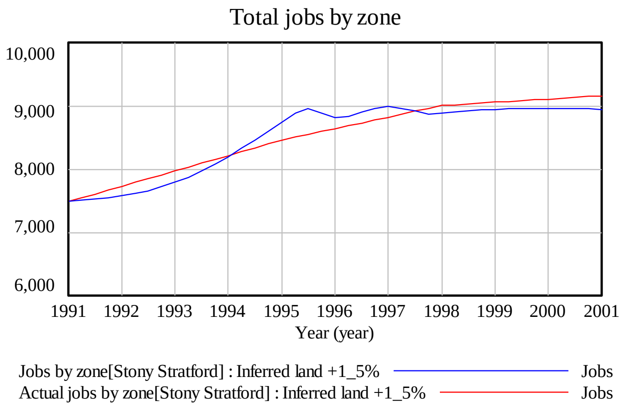
Figure 2 traces some more consequences. The rising business start up rate plus the increase in rents caused by new business activity encourages developers to build more employment premises. The rising stock of premises tends to reduce rents again, increasing attractiveness as a business location. Construction depletes the stock of available land, which may become a constraint on further expansion.

Figure 2: Cause and Effect – providing premises for employers



The outputs from the model are time series for each variable, in tabular or graphical form. Figure 3 illustrates, showing a comparison of two runs of the model.

Figure 3: Example of output from the UDM



Much of the model is more sophisticated than shown here. The transport network models are actually quite conventional, and we commonly import network data from other existing transport models. The novel aspect of the UDM is the way transport modelling has been linked to a range of social and economic factors in a dynamic simulation framework.

Policy Context in the UK

In 2004 the UK Department of Transport introduced a new approach to funding transport investment called the Transport Innovation Fund, or TIF. This was intended to do two things: to improve the productivity of jobs and employers, essentially by extending the recruitment pool for employers and reducing business-to-business costs, but also to manage demand for car travel using methods such as congestion charging.

More recently the Department has issued guidance to help regional authorities develop strategic transport plans and policies, called *Delivering a Sustainable Transport Strategy*, which further emphasises transport's role in supporting economic development.

These policy developments, explicitly linking transport to its wider context in society and the economy, have created a need for a different kind of model; the UDM is designed to meet that need.

An Application in Leeds

Leeds is a city in the north of England with a population of about 800,000, although it is set in a wider area known as Leeds City Region, with a population of 2.8 million. The centre of Leeds has, like many cities, a high concentration of employment and aspirations for growth, but rising traffic congestion is causing concern, to the point that a new strategy was required, with TIF offering a possible way of generating the necessary investment funds. To do this it was necessary to show how investment would help sustain future growth of the Leeds economy.

Building the model

The whole study area extended well beyond Leeds itself, in order to reflect the catchment for recruitment and significant business-to-business movements. The whole modelled area has 146 zones, with 51 covering Leeds city.

These zones were initialised with stocks of people, employment etc taken from publicly available statistics in the UK, including the Census, and annual government surveys of job numbers.

A strategic highways model was built by modifying an existing highways model in SATURN, while rail costs and times came from a rail industry services database ("MOIRA"). Not having a bus network model, bus zone-to-zone costs were inferred on the basis of mode shares observed in the census, essentially by using a mode choice model in reverse; costs for walk and cycle, which account for about 9% of travel to work trips in Leeds, were deduced similarly.

With this base data in place, an extensive process of calibration followed. Tests included:

- Tests that it could reproduce the census observed travel to work matrix; the model does not take matrices as inputs, but generates them internally;
- Tests that it reproduced travel to work mode shares correctly;
- Comparisons of the internally generated drive times with actual drive times measures by electronic sensors on the roads;
- Comparisons of average commute distances with the census and with road side interview data;
- Tests that it could reproduce changes in population and employment seen in Leeds since the census year;
- Comparison of internally generated unemployment rates and job vacancy rates with published statistics.

Using the Model for Scenario Tests

Nearly all local authorities in the UK are faced with rising demand for housing, a consequence of rising population and smaller average household sizes. Leeds has a projected need for an extra 115,000 houses by 2031.

Similarly, the city has aspirations for significant growth in employment, with 10% growth projected in the city centre alone.

Since the aim is to show how transport can help support growth or constrain it, we cannot simply impose this growth on the model. Instead the model was given additional land where this growth is expected to occur, phased over time, and left to simulate whether or not the houses and employment premises would be built and the people or jobs would follow. Scenario tests were then formulated to explore how transport investment could stimulate this growth, or lack of investment could constrain it.

Analysis of a baseline run showed how, on one hand, central Leeds remained an attractive place for businesses, because of its access to a workforce, customers and suppliers, and growth in employment continued, but on the other hand congestion and rising transport costs led to worsening travel conditions, so that the recruitment catchment for the central area actually shrank.

This would normally choke off growth in the centre, but this shrinkage was offset by the rising population. The vision of the future was of more jobs, more people, and ever worsening travel conditions.

Analysis of the changes in travel patterns using GIS suggested that a strategic response would be to develop transit (ie bus) services in corridors serving the central area from, roughly, the city's outer ring road. Tests showed how this could stimulate further growth in the centre, by improving access to a workforce, encouraging mode shift and reducing congestion.

Reflections on using the UDM

New policy guidance in the UK has given rise to the need for a different type of model demonstrating the relationship between transport, society and the wider economy. This is part of the innovation that the UDM brings: its integrated approach to modelling interactions between land, people, employers and transport.

The second innovation is of a technical nature. Neither system dynamics nor transport network models is new, but their successful integration within a dynamic simulation framework is. To the author's knowledge the UDM is the only model of its type and scale to have been used repeatedly and successfully on real practical applications in a variety of urban areas.

The third innovation is a consequence of the first two. Modern system dynamics software offers a modelling environment with advanced error checking, sensitivity analysis, diagnostics and flexible reporting facilities. When used in a disciplined way these help to ensure that models are correctly formulated and operating as intended. The UDM also runs very quickly: the Leeds model can simulate 20 years in 30 minutes; this compares to many hours or even days required by some alternative models.

Finally, although the UDM was developed with the UK context in mind, the question of how to address transport strategy, economic and population growth is universal; this model provides a means to address such problems.

Useful references:

URBAN DYNAMICS, Jay Forrester; 1969, ISBN 1-56327-058-7. Productivity Press. Describes the original model built by Forrester using sustem dynamics

THE IMPACT OF TRANSPORT ON BUSINESS LOCATIONS, report by Steer Davies Gleave for the UK Depaertment for Transport, September 2007. Describes forulation and calibration work on parts of the UDM.

www.Vensim.com: Vensim is the software used to build the UDM.